R&D 6291-EE-01
DAJA45-

1

Novel Optoelectronic Devices based on combining GaAs and InP on Si

Interim report 5

by P. Demeester

1. Introduction

In the last 6 months the work has concentrated on the following topics : use of GaAs on InP heteroepitaxial growth for the fabrication of an optical switching OEIC, development of non-planar growth (SMG) for laser-waveguide coupling using InP based materials, development of selective growth of InP for photonic integrated circuits, optimization of In(Al)GaAs/AlGaAs growth on GaAs , optimization of the epitaxial lift-off technology (ELO).

2. GaAs on InP based OEIC.

The work on heteroepitaxial growth has concentrated on the realisation of an optical switching OEIC. This OEIC integrated a GaAs MESFET driver with an InP optical switch. A schematic representation is shown in figure 2.1 where a cross-section and top view are shown. In a first step the InP/InGaAsP waveguide structures are fabricated (without the metallisations). In a second step one grows the GaAs active layer structure for the MESFETs. This is done selectively in order to protect the waveguide structures. In a next step the optical switches are finished (Zn-diffusion and metallisation) and finally the MESFETs are processed and interconnected with the optical switches. The modulation characteristics of the optical switch (without interconnection) are shown in figure 2.2. About 14 mA is required for the optical switching. Loss measurements showed that the loss in individual waveguides was 0.5 dB/cm but the loss in the switches was increased to 4 dB/cm due to some diffusion of the Au metallisation towards the active waveguiding region. The MESFETs showed a transconductance of 50 mS/mm for a 2 μm gate length. In figure 2.3. we observe the switching behaviour when the MESFET is used for modulation of the switch. A schematic representation of the circuit diagram is also shown. A V_{gs} voltage of 1.2 V was required for switching. This is also shown in figure 2.4 where we observe the modulation voltage (bottom) and the light modulation (top). A modulation by 1 V resulted in a light modulation of about 6 dB.

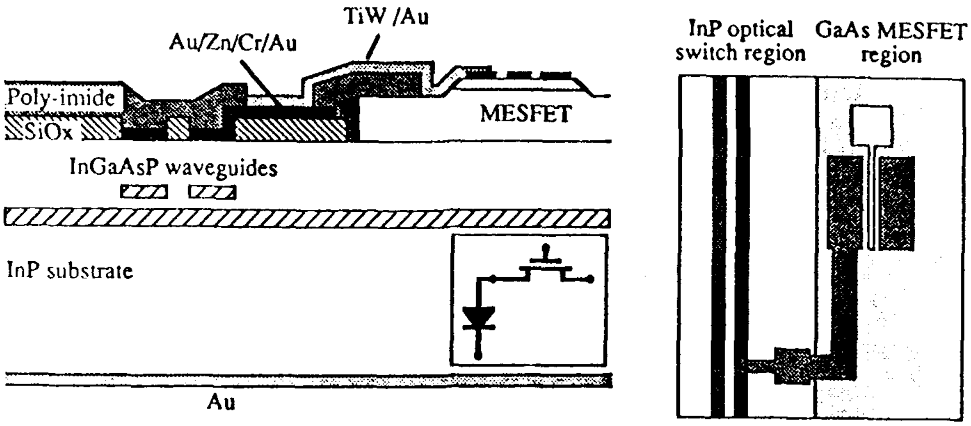

Figure 2.1. Integration of a GaAs MESFET and an InP optical switch using heteroepitaxial growth.

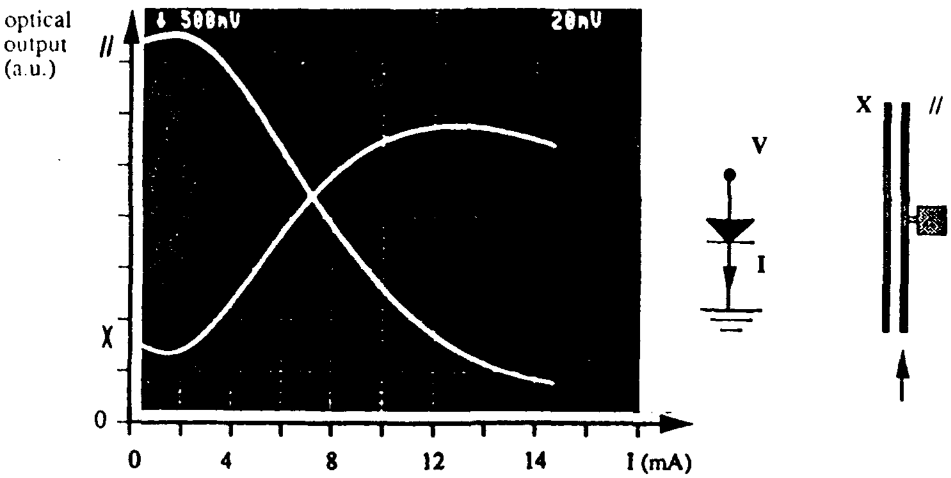

Figure 2.2. Switching behaviour of the optical switch alone (using current injection).

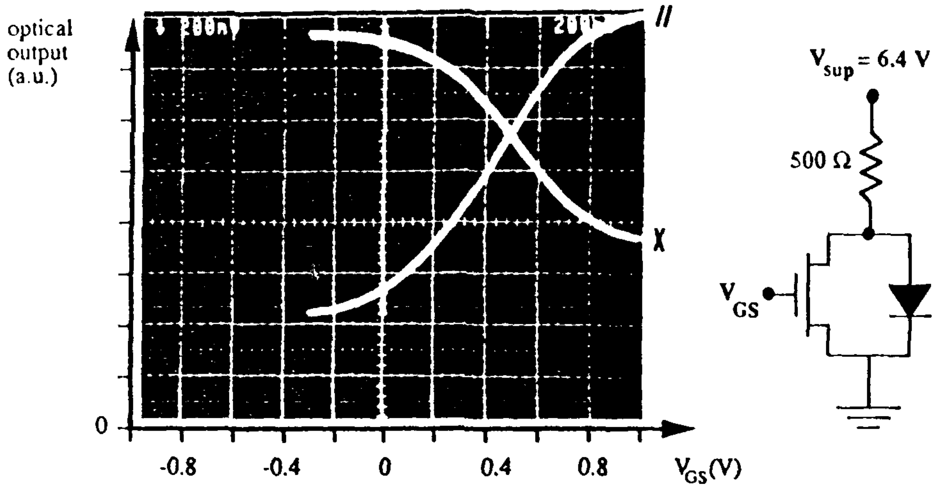

Figure 2.3. Switching behaviour of the optical switch combine with the GaAs MESFET driver.

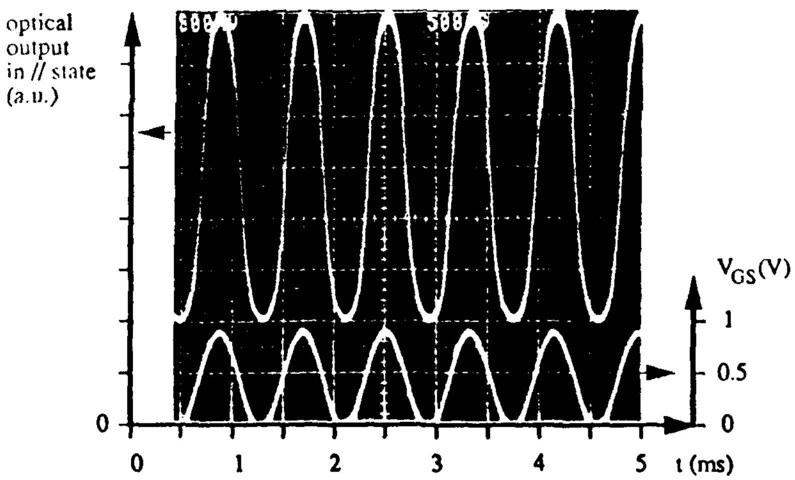

Figure 2.4. Modulation of the optical switch : input is V_{gs} (lower curve), output is optical signal (upper curve)

3. Non-planar growth on InP

The shadow masked growth technique described in the previous interim reports has been further investigated. In the last reports we have concentrated on the GaAs material system but in the last 6 months we have investigated InP based materials. An additional problem with this material system is that the variation in composition due to the shadow masked growth will also result in a variation of the lattice constant. If this variation becomes to large it will result in a bad material quality. In figure 3.1 we observe the variation of the growth velocity as a function of window width (of the shadow mask) for InGaAs material when using atmospheric and low pressure growth. The variation with spacer layer thickness is also shown. We clearly observe a similar behaviour as for the GaAs growth but an interesting feature is certainly the dependence of reactor pressure. At low pressure we observe a reduced influence of the window width variation. Figure 3.2. shows the variation in composition of InGaAs material. We clearly observe a variation in the composition of the grown material. Figure 3.3 shows the variation in emission wavelength (bandgap) of a InGaAs/InP quantum well. We clearly observe a strong dependence on the window width. Note that the variations in composition (figure 3.2) and in thickness applied to QWs (figure 3.1) are in the same direction.

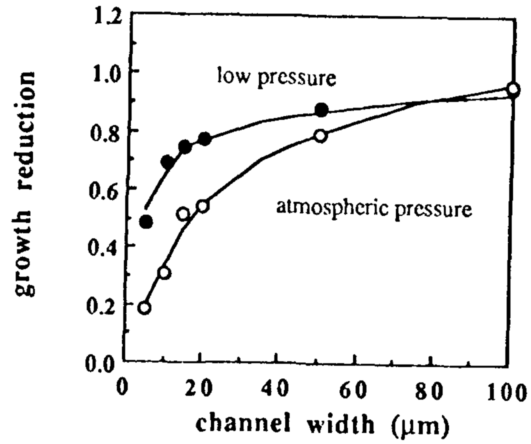

Figure 3.1. Variation of the growth velocity of InGaAs as a function of the channel width

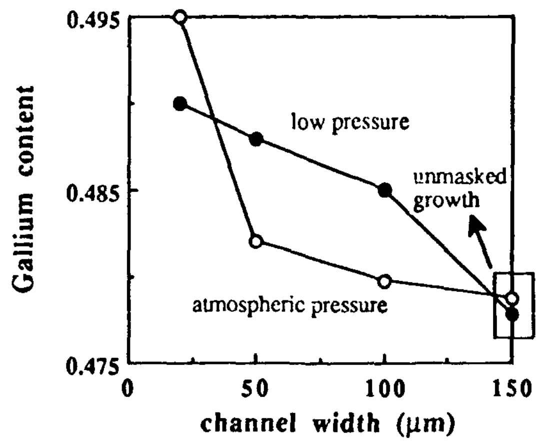

Figure 3.2. Variaton of the compostion of InGaAs as a function of the channel width.

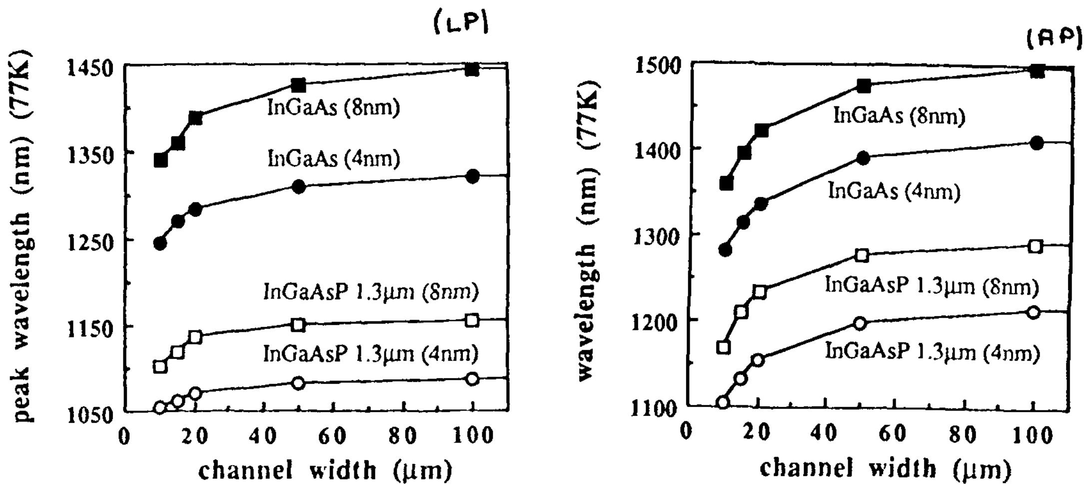

Figure 3.3. Variation of the bandgap (emission wavelength) of InP/InGaAs(P) quantum wells as a function of the window width.

5. Selective growth of InP based materials

We have very recently started to investigate an alternative very promissing possibility to the shadow masked growth technique. The principle is shown in figure 5.1. Two fairly small SiO_2 stripes (typically below 10 μm) are deposited on the substrate with a spacing in the range of 2 to 10 μm. There will be no deposition on the oxide and therefore material will diffuse towards the stripe inbetween the oxide stripes. This will result in an enhanced growth velocity and a variation in composition. A similar investigation as for SMG was performed. Figure 5.2. gives the variation in growth velocity as a function of the oxide width. We clearly observe that the variation is much larger when growing at atmospheric pressure (similar to the observations when using SMG). The variation in composition of bulk material is shown in figure 5.3. and the bandgap variation for QWs is shown in figure 5.4. It is clear from the obtained

results that there are a large number of applications which will benifit from this growth technique.

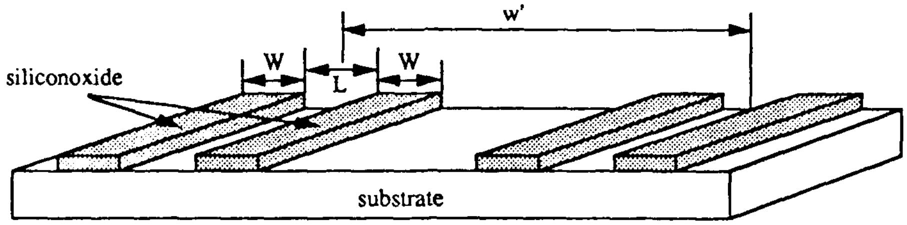

Figure 5.1. Principle of selective growth

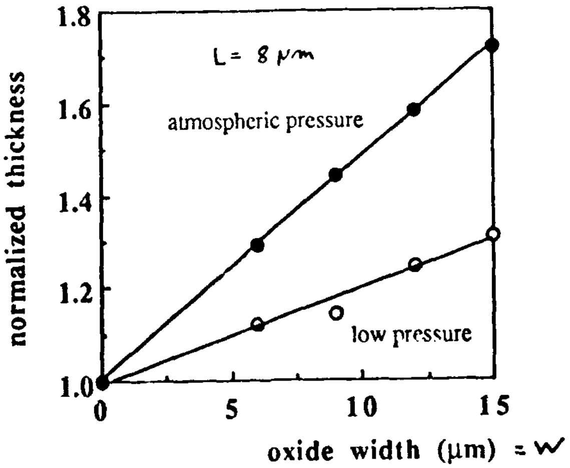

Figure 5.2. Variation of the growth velocity as a function of the oxide stripe width.

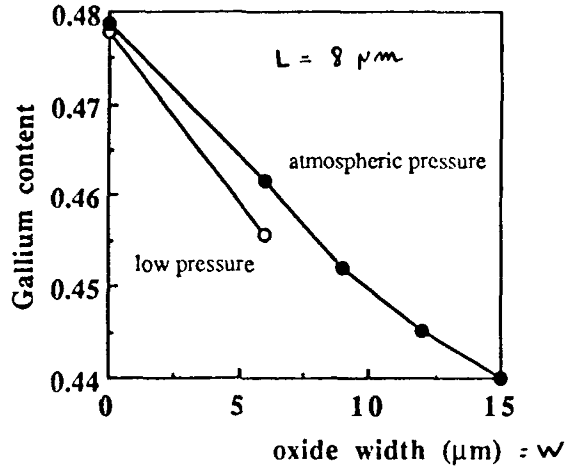

Figure 5.3. Variation of the composition of InGaAs as a function of the oxide stripe width.

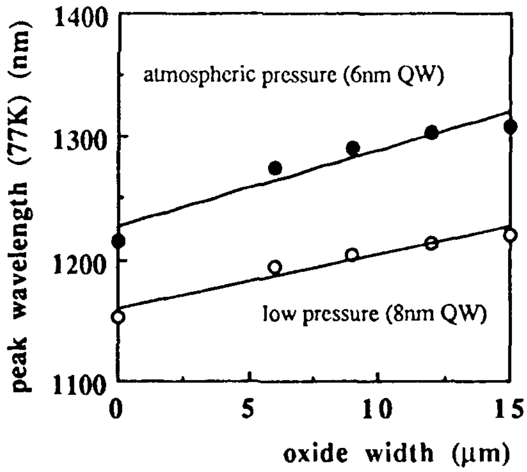

Figure 5.4. Variation of the bandgap (emission wavelength) of InGaAs(P)/InP quantum wells as a function of the oxide stripe width.

6. Growth of InGaAs/AlGaAs strained MQWs

We have described in the last interim report the use of InAlGaAs QWs for the fabrication of strained layer QW laser diodes. These preliminary results were very promising but a further improvement of the growth parameters was required. In figure 6.1. we show the variation of photoluminesence intensity with the growth temperature for InAlGaAs/AlGaAs quantum wells. It is clearly observed that an increasing temperature results in improved QW performances. Figure 6.2. shows some examples of photoluminescence spectra obtained on these samples.

In the last report we have also described some promising results on InGaAs/AlGaAs MQW vertical optical modulators. One of the major remaining problems however was the high insertion loss of these modulators. Figure 6.3. shows the reflection characteristics at different applied voltages for a novel modulator structure. We observe that the insertion loss can be reduced below 2 dB. The modulation is 6.4 dB at a driving voltage of -10 V (see figure 6.4).

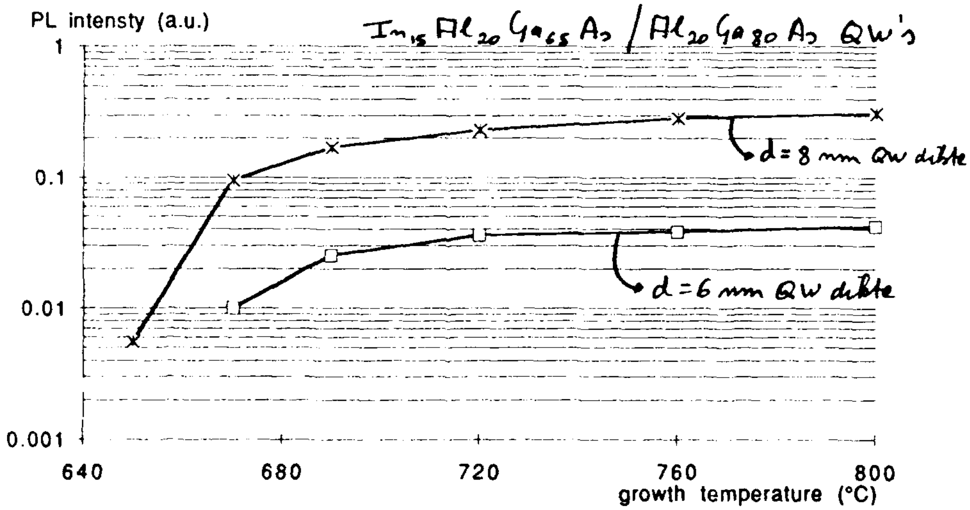

Figure 6.1. Variation of the photoluminescence intensity as a function of the growth temperature for InAlGaAs/AlGaAs quantum wells.

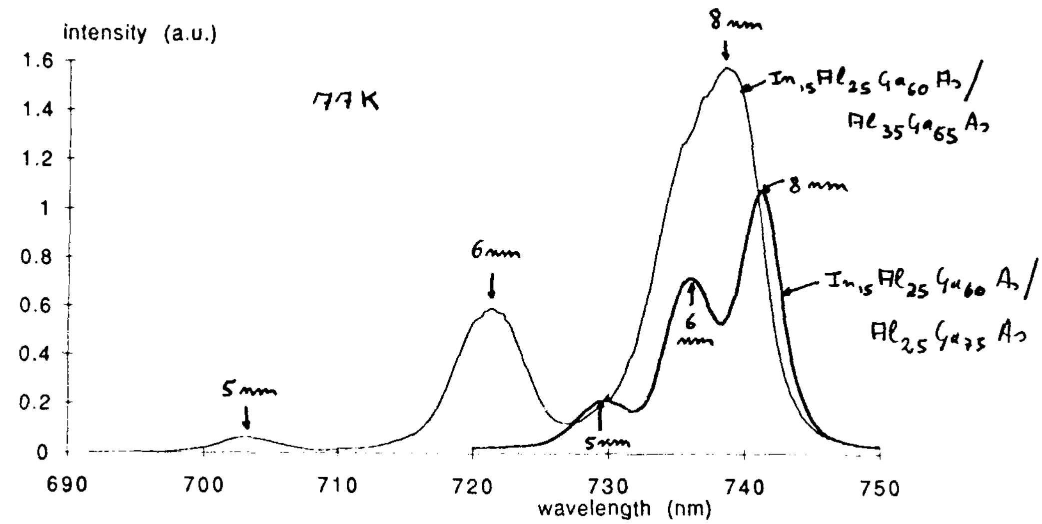

Figure 6.2. Examples of photoluminescence spectra of InAlGaAs/AlGaAs strained quantum wells

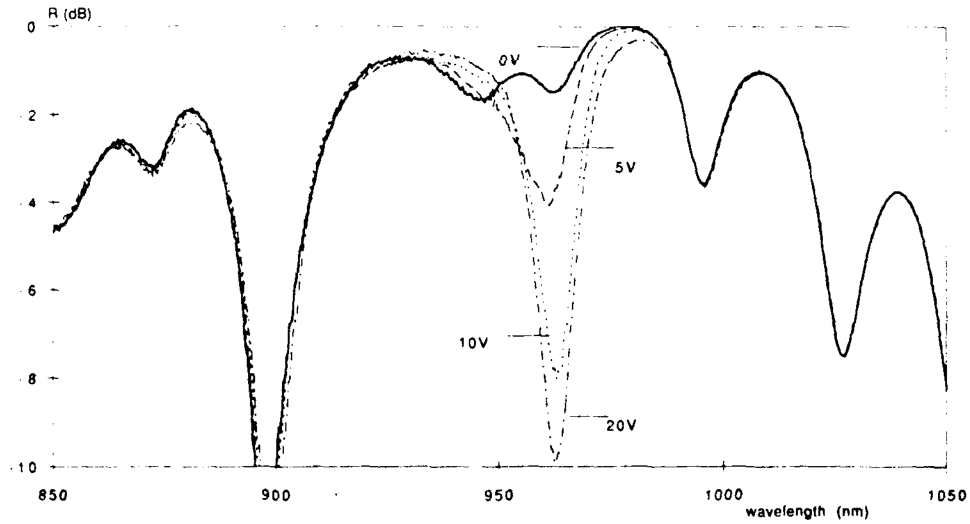

Figure 6.3. Reflection curve of a normally off modulator with low insertion loss.

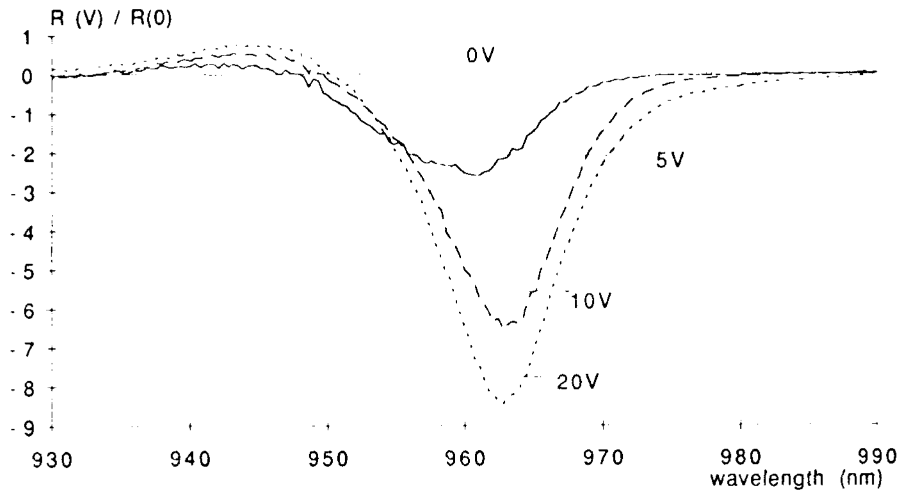

Figure 6.4. Modulation characteristic of a normally off modulator with low insertion loss.

7. Epitaxial Lift-Off (ELO)

The work on epitaxial lift-off has progressed considerably. A basic issue is now the further consolidation of the basic technology. It has been shown in the last report that very low driving voltages can be obtained for a GaAs on InP optical switching OEIC. During the last 6 months we have concentrated on optimizing further the basic technology. It has been shown that the high frequency characteristics are similar before and after epitaxial lift off (see figure 7.1). Much effort was put in the optimization of the bonding of ELO films onto polyimide layers on InP. It was shown that by using a proper bake-out step (at 150 °C) the bond strength could be drastically improved. Finally we have done some life-time measurements on GaAs MESFETs before and after lift-off. The initial results are very promising, as shown in figure 7.2.

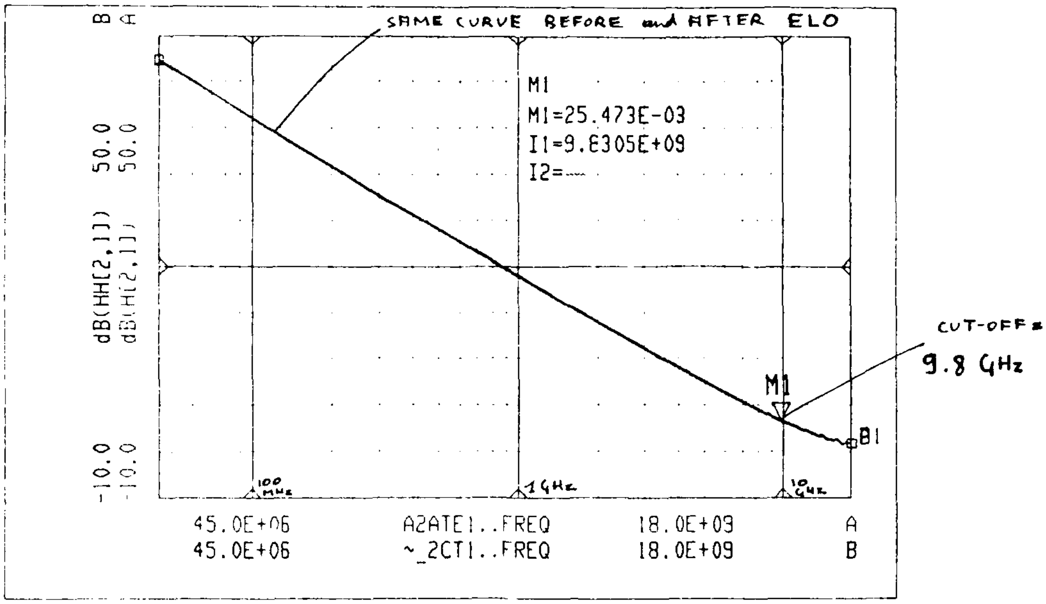

Figure 7.1. High frequency behaviour of GaAs MESFETs before and after ELO.

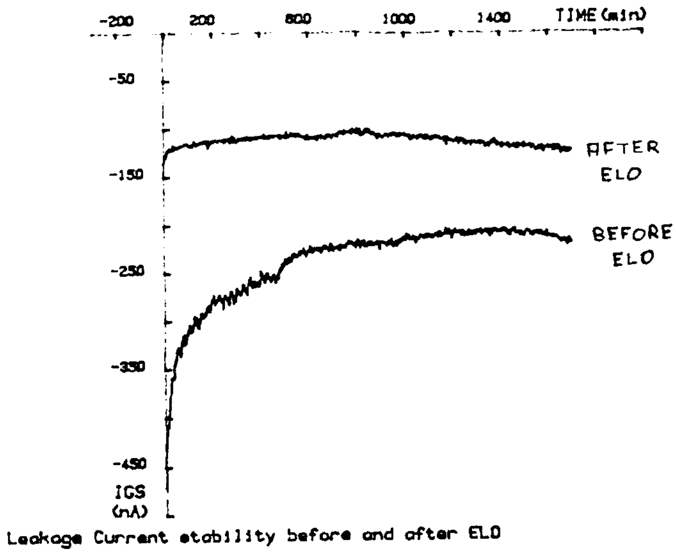

Figure 7.2. Stability test of GaAs MESFETs before and after ELO.

6. Conclusion

In this fifth report we have descibed some of our most recent results on the fabrication of novel optoelectronic devices. The work has progressed rapidely and some very new results have been obtained : heteroepitaxial GaAs on InP optical switching OEIC, SMG growth of InP materials, selective growth of InP materials, high quality and low insertion loss InGaAs/AlGaAs asymmetric fabry-perot vertical modulators, improved material quality of InAlGaAs/AlGaAs QWs and the furhter optimization of the ELO technology (good high frequency behaviour, improved bonding and good stability).

references

I. Pollentier, L. Buydens, P. Demeester, P. Van Daele, A. Enard, E. Lallier, G. Glastre and D. Rondi, "Monolithic integration of a GaAs MESFET and an InP/InGaAsP 2x2 optical switch", accepted for publication in El. Lett.

L. Buydens, P. Demeester, P. Van Daele, "Asymmetric Fabry-Perot modulators with an InGaAs/AlGaAs active region", accepted for publication in Optical and Quantum Electronics.

P. Demeester, G. Coudenys, G. Vermeire, Y. Zong-Qiang, I. Moerman, L. Buydens and P. Van Daele;" Novel growth techniques for the fabrication of Photonic integrated circuits" Invited paper to be presented at the MRS Fall meeting, Boston, dec 1991

L. Buydens, P. Demeester, Z. Yu, P. Van Daele; "High-Contrast / Low-Voltage normally on InGaAs/AlGaAs asymmetric Fabry-Perot modulator", paper accepted for publication in Photonics Technology Letters.